EGU26-416, updated on 23 Oct 2026
https://doi.org/10.5194/egusphere-egu26-416
EGU General Assembly 2026
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Flexure Modeling of Plume Ascension on Mars

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Near the equator of Mars, between the branched valleys of Noctis Labyrinthus and Valles Marineris, a large rift system, lies a heavily fractured and eroded region, whose tectonic history is poorly constrained. In this region, an eroded shield volcano, named 'Noctis Mons', was recently identified through satellite imaging (Lee & Shubham, 2024). Its complex topography makes it difficult to provide a clear chronology of events that led to its formation and erosion. Processes such as plume uplift, fracturing and interaction with the Valles Marineris rift system, gravitational collapse, and the contact of hot volcanic materials with shallow subsurface ice likely played an important role for shaping this volcanic construct.

In this work, we test the hypothesis that an ascending mantle plume is responsible for the unique features of Noctis Mons. We first model a rising plume using the geodynamic code GAIA (Hüttig et al., 2013). The Tharsis province represents a large-scale and thick regional crustal thickness anomaly that we incorporate into our plume model by adding a step-like function to evaluate the influence of varying crustal thickness on an ascending plume. We further test several parameters that control the plume dynamics and morphology, including the distribution of heat sources between the mantle and crust, the thermal conductivity of the crust and mantle, the depth-dependence of the viscosity, as well as the consideration of partial melting and melt extraction. Once the plume reaches the base of the lithosphere, we use the GAIA-generated plume temperature distribution to compute crustal deformation. We evaluate flexural uplift and strains in response to this plume to identify regions of extension using a methodology similar to (Broquet & Andrews-Hanna, 2023). The density variations of the plume generated by our geodynamical models is used to solve a system of flexure equations for dynamic uplift, accounting for horizontal and vertical loading as well as self-gravity effects. We iterate both the plume characteristics produced by the geodynamical model and its induced crustal deformation until we find an optimal scenario that reproduces Noctis Mons' topography and predicts extensional features similar to Noctis-related graben systems seen in satellite images and topography. We also analyze present-day gravity and topography to characterize the rigidity of the lithosphere and the density of the materials composing Noctis Mons.

With our computational framework we aim to constrain the magmatic behavior as well as thermophysical and rheological parameters for the crust and mantle that led to the complexity of tectonic features observed at Noctis Mons, informing our understanding of the formation and evolution of volcanic constructs on Mars.

Studying plume ascent near Noctis Mons further informs our understanding of volcanism on Mars in its early history. Recent seismic recordings from the InSight lander reported activity in Elysium Planitia, indicating a potential upturn in tectonic activity. We will apply our ascending mantle plume model to Elysium Planitia, a region near Mars' equator, that potentially hosts a giant and presently active mantle plume (Broquet & Andrews-Hanna, 2023).